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SOME STUDIES ON THE USE OF NASTRAN FOR NUCLEAR POWER PLANT STRUCTURAL ANALYSIS AND DESIGN

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SUMMARY

This paper presents some of the studies made on the use of NASTRAN for nuclear power plant analysis and design. These studies indicate that NASTRAN could be effectively used for static, dynamic and special purpose problems encountered in the design of such plants. Normal mode capability of NASTRAN is extended through a post-processor program to handle seismic analysis. Static and dynamic substructuring is discussed. Extension of NASTRAN to include the needs in the civil engineering industry is discussed.

INTRODUCTION

With the ever increasing size of nuclear power plants now under construction and those comtemplated in the future coupled with growing concern of the owner, engineer, regulatory bodies and the public on the quality and safety of such plants, a greater emphasis is continuously being laid on the specification of more reliable loads and material properties together with more sophisticated tools and procedures for analysis and design. Anticipating this trend, Pioneer Service & Engineering Co. initiated a study of the currently available computer programs in the area of statics, dynamics and stability of structures including capabilities for handling physical and geometric nonlinearities. It was quickly realized that no single computer program would be uniformly effective for such a broad spectrum of requirements. However, it was also found that NASTRAN was the best candidate to handle a major portion of the requirements. It is not the intent of this paper to enumerate the capabilities of NASTRAN. Only those features which were found particularly useful are mentioned in the sequel.

A typical pressurized water nuclear power plant structure consists of several buildings which may be connected to one another at the foundation level and/or at several higher elevations. The reactor shield building is typically a reinforced or pre-stressed concrete cylindrical shell with a spherical or elliptical cap. The adjoining buildings and the internals of the reactor building have shear walls as their lateral load carrying elements. Thus, the entire structural system consists of a complex of shear

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walls, slabs, pre-stressed shells, and steel or concrete columns and roof structure as seen in Figures 1 and 2. This system has to be analysed for several load conditions and their pre-assigned combinations. These load conditions are static (e.g. dead and live loads) or dynamic (e.g. base excitation due to earthquake ground motion) in nature. Hence, a program which uses the data base and matrices generated for the static problem to perform a dynamic analysis would be most suited for such combinations. This capability is found in NASTRAN and is an important advantage over other programs.

Features in NASTRAN, Level 15.1, which would be required for the efficient processing of static and dynamic problems were checked out using simple models. Some of the experiences are discussed below. Since NASTRAN does not support modal spectral analysis for base excitation and does not combine static and dynamic results, post-processors were developed for these specific tasks and are briefly presented. Finally, some suggestions for incorporating new features in NASTRAN which would be effective in civil engineering structural analysis are noted.

SUBSTRUCTURING

Anticipating that the structural model of the entire power plant for static and dynamic analyses would result in a large number of degrees of freedom, and also noting that the structures within the total system have well defined boundaries, it was found that the substructuring technique would be a logical and effective approach. To make efficient use of the features available in NASTRAN, the intermediate results obtained from static substructuring should be used for the dynamic analysis or vice versa. The schematic diagram shown in Figure 3 uses the above feature. Post-processing phases are also shown in the figure. All interfacing between the post-processors and NASTRAN is accomplished through NASTRAN generated data blocks placed on tape or disks using OUTPUT2 module.

The scheme shown in Figure 3 was tested using the simple plate problem given in the Demonstration Manual (Reference 1). The 5 x 10 element half-plate model is shown in Figure 4. Symmetric boundary conditions were assumed along the line of symmetry. Inplane deflections and normal rotations are constrained. The half-plate model is arbitrarily separated into two substructures, referred to as SUB 1 and SUB 2. Two load cases for the static problem and the simply supported boundary conditions were specified in Phase I. The static problem was run first with the symmetric boundary conditions specified in Phase II. This was done so that, if results for antisymmetric conditions were necessary at a later stage, they could have been obtained without going through Phase I again. Slight changes to the ALTER package for substructuring as given in the User's Manual (Reference 2) were made so that the OUTPUT1 data blocks of the two substructures could be placed on the same tape. The results of the static analysis were printed and placed on tape using the OUTPUT2 module. The dynamic analysis was carried out utilizing the stiffness matrix generated in Phase I of the static analysis. The mass matrix was not generated in the static part since no GRAV loads were applied, hence, Phase I of the dynamic analysis using the stiffness matrix KAA of the static part and using a restart with a rigid format switch was executed. In this phase only the mass matrix was computed. If a GRAV load was introduced in the static analysis, the MAA matrix would have been generated and stored. Then, it would not have been necessary to run the Phase I of the dynamic analysis. Modes and frequencies of vibration of the example problem agreed very well with those given in the Demonstration Manual.

Phase III of the dynamic analysis was successfully completed using check pointed tape of Phase I static analysis and with a switch in rigid format. However, it was found that attempting Phase III of the dynamic analysis using the check pointed tape of Phase I of the dynamic analysis, which, in turn, was generated from the check pointed tape of Phase I of the static problem, resulted in a fatal error. In other words, multiple restarts were unsuccessful.

SEISMIC ANALYSIS

The seismic analysis of a structure can be approached in two different ways, (a) by the modal analysis using the ground response spectra and combining the individual modal responses in a predetermined procedure (e.g. square-root-of-sum-of-the-squares); and (b) by modal or direct integration of the equations of motion using a given time-history of ground acceleration. These approaches and their pros and cons are discussed in any standard book on earthquake engineering (e.g. Reference 3) and hence, will not be detailed here. In practice, the first approach is more commonly used because of its simplicity and the ease of defining the inputs. Hence, this approach will be discussed in what follows.

The dynamic models of the total structural system used by other investigators (References 4 and 5) are shown in Figure 5. The first of these two models involves the assumption that the individual buildings and their internals can be lumped to form a set of cantilever "flagpoles". The complex arrangement of the buildings together with their low profile makes this assumption a gross one. The second model assumes that the shear walls can be represented as horizontal springs and the floor as a rigid diaphragm. This would have been a valid assumption for a tall building but is not entirely applicable for nuclear plant structures.

Our approach is to model the vertical shear wall elements and the horizontal slabs using membrane and plate elements of NASTRAN. This would result in a structural model with a large number of degrees of freedom. It is, however, not essential nor economical to retain all of these degrees of freedom in the dynamic analysis. Hence, substructuring and Guyan reduction are necessary. The pertinent equations for seismic analysis of the structure using the modal approach are given below.

$$I_H \ddot{U}_H + B_{HH} \dot{U}_H + K_{HH} U_H = -\phi_A^T M_{AA} \ J \ a_g \tag{1}$$

where M, B, K, and I are the mass, damping, stiffness, and identity matrices, subscripts H and A refer to the modal displacement and analysis sets respectively in Phase II of the substructuring procedure, ϕ is the mass normalized eigenmatrix, J is an A x 3 matrix of ones and zeroes which selects the masses which excite the motion in the given directions, and a_g is 3 component vector of the ground acceleration time-history. It is noted that the matrices on the left hand side are all assumed to be of the diagonal form representing uncoupled modal equations.

The matrix product

$$\phi_A^T M_{AA} J$$

represents the participation factors, PF, of each mode for each of the three components of ground motion. These quantities are computed in NASTRAN through the following ALTER package for Rigid Format 3.

```
ALTER 93
MPYAD MAA, PHIA, /X/C, N, O/C,N, 1/C, N, O/C, N, 1 $
MPYAD J, X, /PF/C, N, 1/C, N, 1/C, N, O/ C, N, 1 $
MATPRN PF , , , , / / $
ENDALTER
```

The matrix J is supplied to NASTRAN through DMI bulk data cards. Since the J matrix depends on the a-set of Phase II, care should be exercised to keep track of the degrees of freedom which are present and the order of their occurrence in the a-set.

In Phase III of the substructuring procedure, the results of the modal analysis for each substructure are printed out as well as made available on tape or disk through the OUTPUT2 feature. The DMAP alter package for Rigid format 3 is given below

```
ALTER 107
OUTPUT2 OPHIG, OQG1, OEF1, OES1, //C, N, -1/C, N, 11 $
OUTPUT2 , , , , / / C, N, -9/C, N, 11 $

ENDALTER
```

The modal results of each substructure are post-processed using the above output values, the acceleration response spectra and the participation factors to obtain the individual modal contributions of the processed quantity. For the i-th mode, the modal contribution for the displacement at a point j for the component of ground motion along X- direction is given by

$$d_j^i\ (X) = \frac{S_a^i}{\omega_i^2}\ PF^i\ (X)\ .\ \phi_j^i \tag{2}$$

where S_a^i is the spectral response acceleration for i-th frequency. The response acceleration spectra are derived from the acceleration time-history, a_g.

The total displacement at the point j for X- direction ground motion is approximated as

$$d_j\ (X) = [\Sigma_{i=1}^{N}\ (d_j^i\ (X)\ )^2\ ]^{\frac{1}{2}} \tag{3}$$

Finally, the total displacement at the point j for the three component earthquake motion is obtained as

$$d_j = [\ (d_j\ (X)\ )^2 + (d_j\ (Y)\ )^2 + (d_j\ (Z)\ )^2\ ]^{\frac{1}{2}} \tag{4}$$

Similar expressions are used for combining forces, stresses etc. The final results are again placed on a tape or disk in a format similar to that of NASTRAN. This makes it convenient to combine the results of static and dynamic analyses.

SUGGESTED ADDITIONS TO NASTRAN FOR CIVIL ENGINEERING NEEDS

a. The single most useful addition to NASTRAN would be the ability to specify loads within the span of BAR elements and the cabability of obtaining output at intermediate cross sections within the BAR element.

b. Capability of specifying different acceleration magnitudes at different mass point for the same load case in the static rigid format rather than a single acceleration value presently available. This feature would, then, be useful in approximating the seismic analysis as a quasi-static analysis for structures where such approximation is permissible.

c. Capability of specifying non-linear relationship between stress resultants and corresponding deformations (e.g. moment-curvature relation) for use in conjunction with the BAR elements. This would allow elasto-plastic analysis of three-dimensional frames.

d. For CQUAD2 and CTRIA2 elements, at present, only bending stress resultants (forces) are printed. The output should also include membrane forces.

CONCLUDING REMARKS

Some studies have been conducted on the use of NASTRAN for nuclear power plant analysis and design. These studies indicate that NASTRAN could be effectively used for such problems. DMAP alter packages and post-processors have been written to extend NASTRAN's capability to seismic base excitation problems. Static and dynamic analysis using substructures have been attempted with switch in rigid format restarts. Post-processors for combining static and dynamic (seismic) solution have been written for use in design sub-routines. Finally, some additions to NASTRAN are suggested which when implemented would make the program more effective in solving civil engineering structural analysis problems.

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5. Bergstrom, Richard N., Chu, Shih-Lung, and Small, Robert J.: Seismic Analysis of Nuclear Power Plant Structures. Journal of the Power Division, A. S. C. E., Vol. 97. No. PO2, March, 1971.

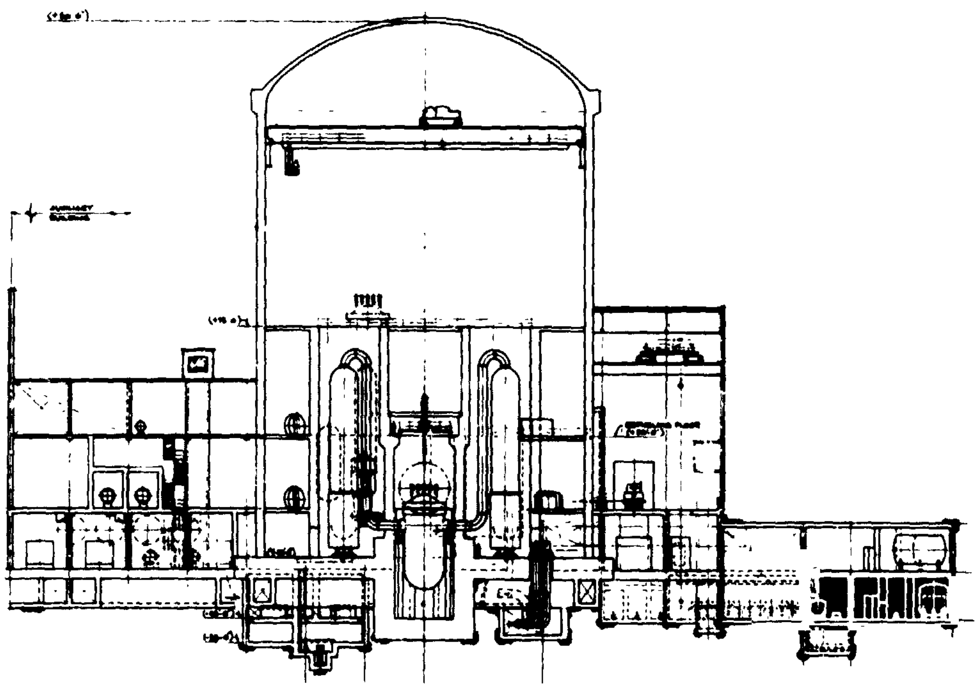

Figure 1.- Section of typical pressurized water nuclear power plant structure.

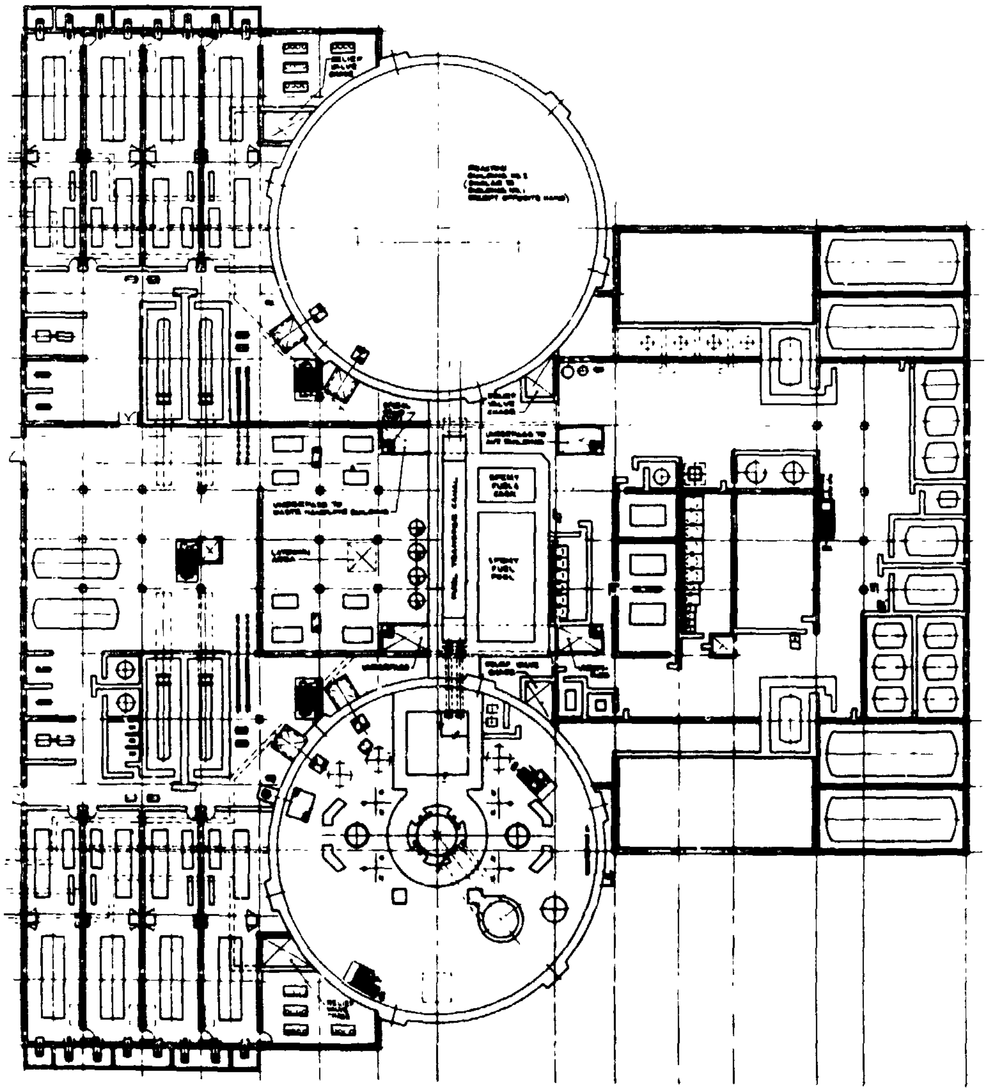

Figure 2.- Plan of typical pressurized water nuclear power plant structure.

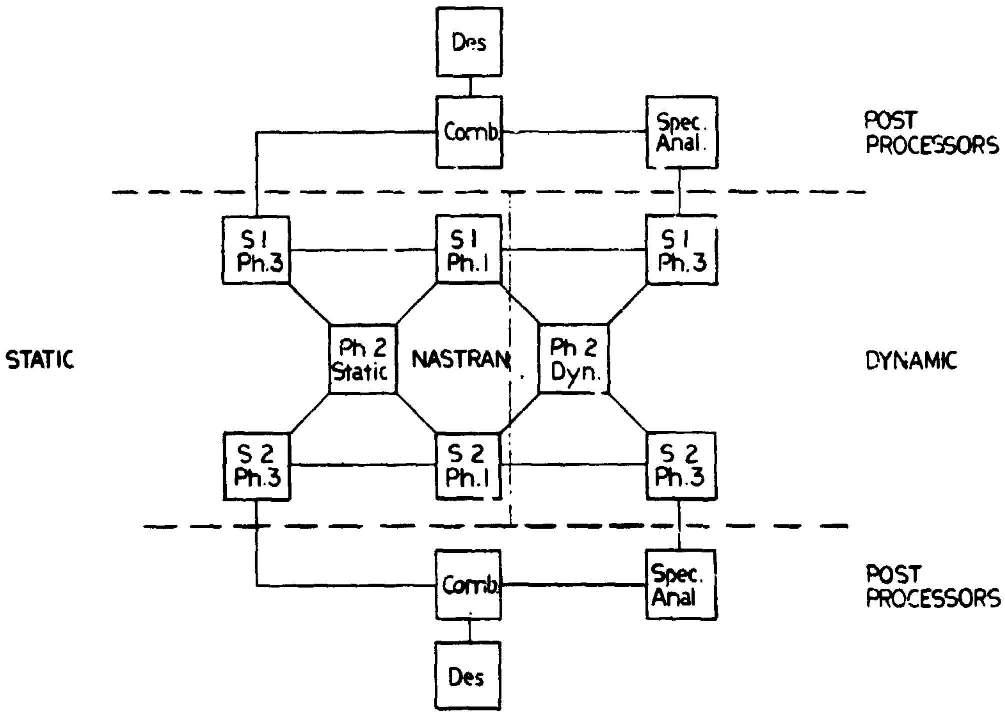

Figure 3.- Block diagram for two substructures.

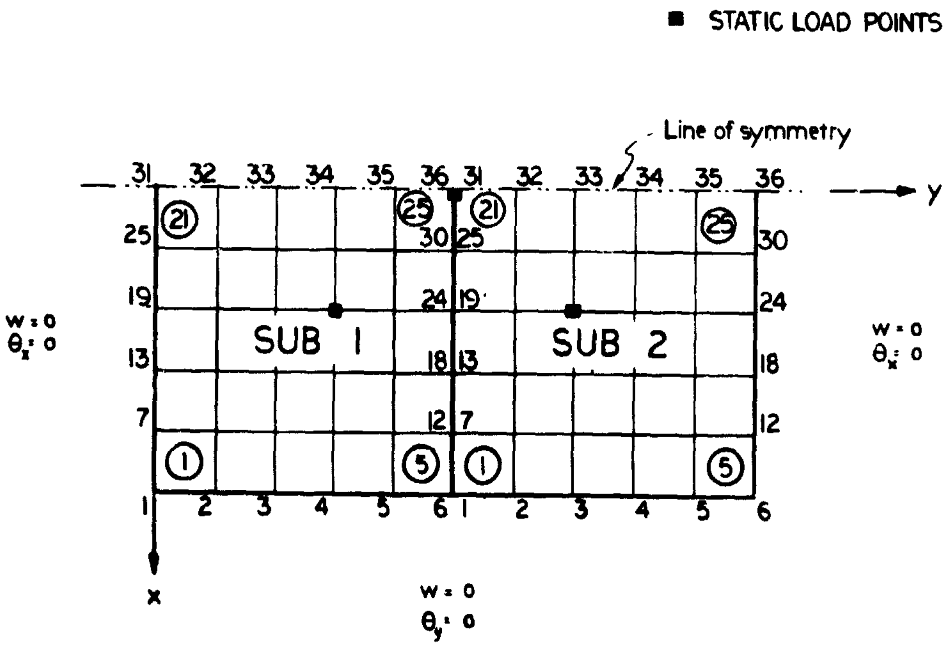

Figure 4.- Example for static and dynamic substructuring.

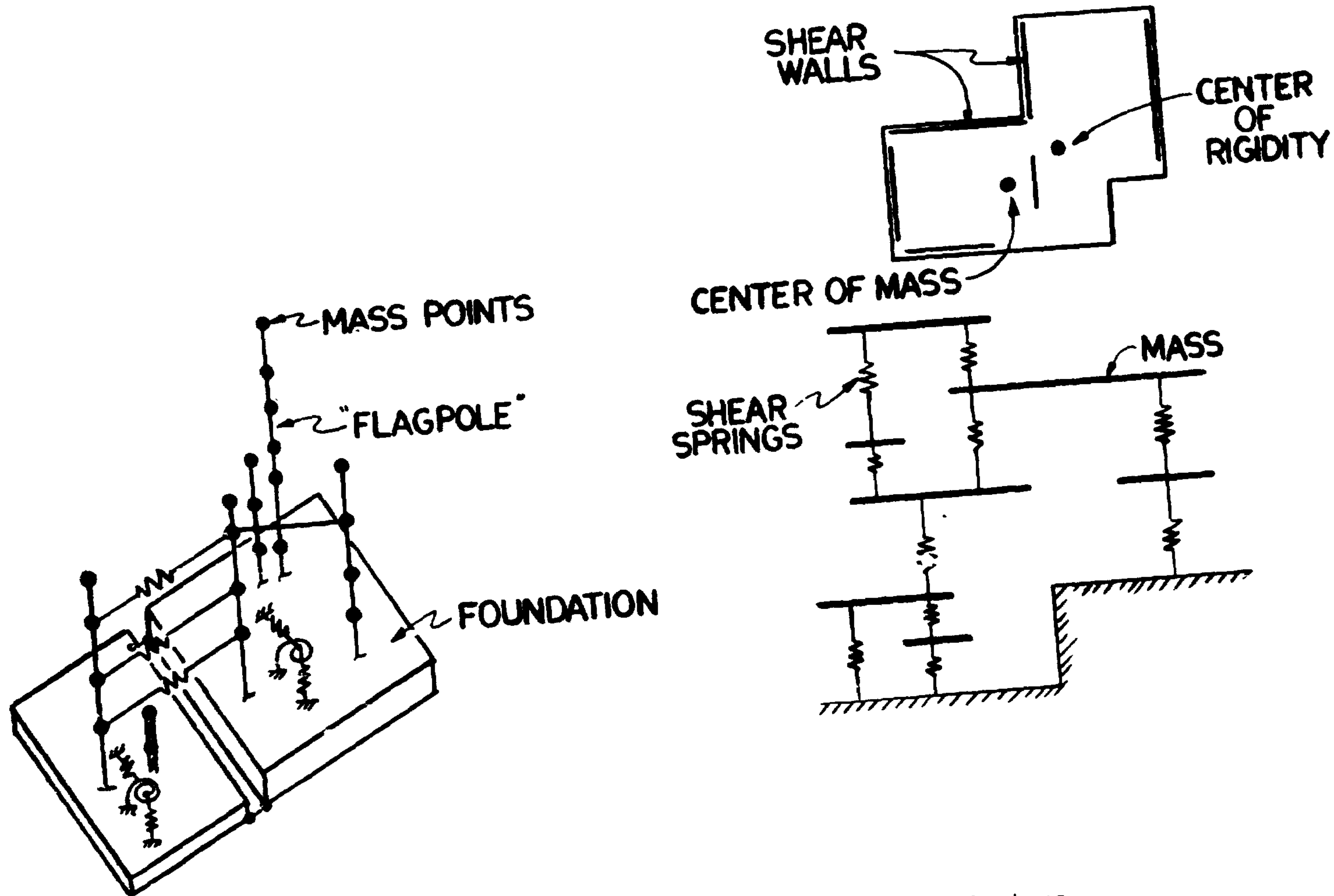

Figure 5.- Dynamic models used by other investigators.